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Eidgenössisches Institut für Metrologie METAS

Physikalisch Technische Bundesanstalt PTB

EURAMET.L-K3.2009.2

Angle comparison using an autocollimator

Bilateral follow-up comparison between PTB and METAS

Final

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Wabern, October 2017

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1 Document control

Version Draft A.1 Issued in September 2017
Version Draft B.1 Issued in 11 October 2017

2 Introduction

This is a bilateral follow-up comparison to EURAMET.L-K3.2009, which was piloted by PTB. Due to large interpolation errors of the angular reference table, METAS had to withdraw measurement results from the afore mentioned comparison. Meanwhile these interpolation errors could be corrected for and METAS asked the pilot to carry out a bilateral comparison in order to confirm its CMCs. The technical protocol did follow the protocol of EURAMET.L-K3.2009.

3 Organization

3.1 Participants

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
PTB	Andreas Just Physikalisch Technische Bundesanstalt 5.21 Length and Angle Graduations Bundesallee100 D - 38116 Braunschweig Germany	Tel. +49 531 592 5221 e-mail: andreas.just@ptb.de
METAS	Rudolf Thalmann Federal Institute of Metrology METAS Lindenweg 50 CH-3003 Bern-Wabern Switzerland	Tel. +41 58 387 03 85 e-mail: rudolf.thalmann@metas.ch

PTB provided the autocollimator, made stability measurements, collected the results and made a first analysis. METAS drafted the technical protocol, analysed the results and wrote the report. PTB provides the link to the preceding comparison EURAMET.L-K3.2009. In this regard PTB's results may be considered as reference results, in particular since it declares considerably smaller uncertainties than METAS and its results were consistent with the key comparison reference values of EURAMET.L-K3.2009.

3.2 Schedule

Table 2. Schedule of the comparison.

RMO	Laboratory	Original schedule	Date of measurement	Results received
EURAMET	PTB	January 2017	November 2016	n.a.
EURAMET	METAS	March 2017	March 2017	May 2017
EURAMET	PTB	April 2017	May 2017	n.a.

4 Artefacts

4.1 Description of the standard

For this comparison, an electronic autocollimator type Elcomat 3000 by Möller-Wedel Optical GmbH (MWO), Wedel, Germany, has been kindly made available by PTB.
As the participants were provided with a detailed technical manual of the autocollimator, only its basic properties are summarised here shortly:

- Two axis electronic autocollimator (the comparison will be performed on the horizontal x-axis only)
- Measuring range: 2000 x 2000 arcsec (up to 2.5 m distance to the reflector)
- Highest resolution: 0.001 arcsec
- Focal length: 300 mm
- Diameter of the illuminated (effective) aperture: 32 mm (tube diameter: 65 mm)
- Dimensions: 420 x 95 x 135 mm
- Weight: 3.8 kg
- Serial number S.N. 1192

4.2 Stability of the standard

PTB calibrated the device in November 2016 and in May 2017. The following graphs show the difference between the two measurement together with the expanded uncertainty (k = 2) of each measurement, Fig.1 without and Fig.2 with correction for the difference of atmospheric pressure between the two measurements, the November 2016 measurement carried out at (997 ± 2.5) hPa and the May 2017 measurement carried out at (1011 ± 2.3) hPa (see section 7.2 for more details about pressure correction). Within the measurement uncertainty there is no significant instability that would affect the results of this comparison. The pressure corrected results do not improve the agreement between the two stability measurements, however the combined uncertainty of the difference becomes also larger due to additional terms from the pressure correction.

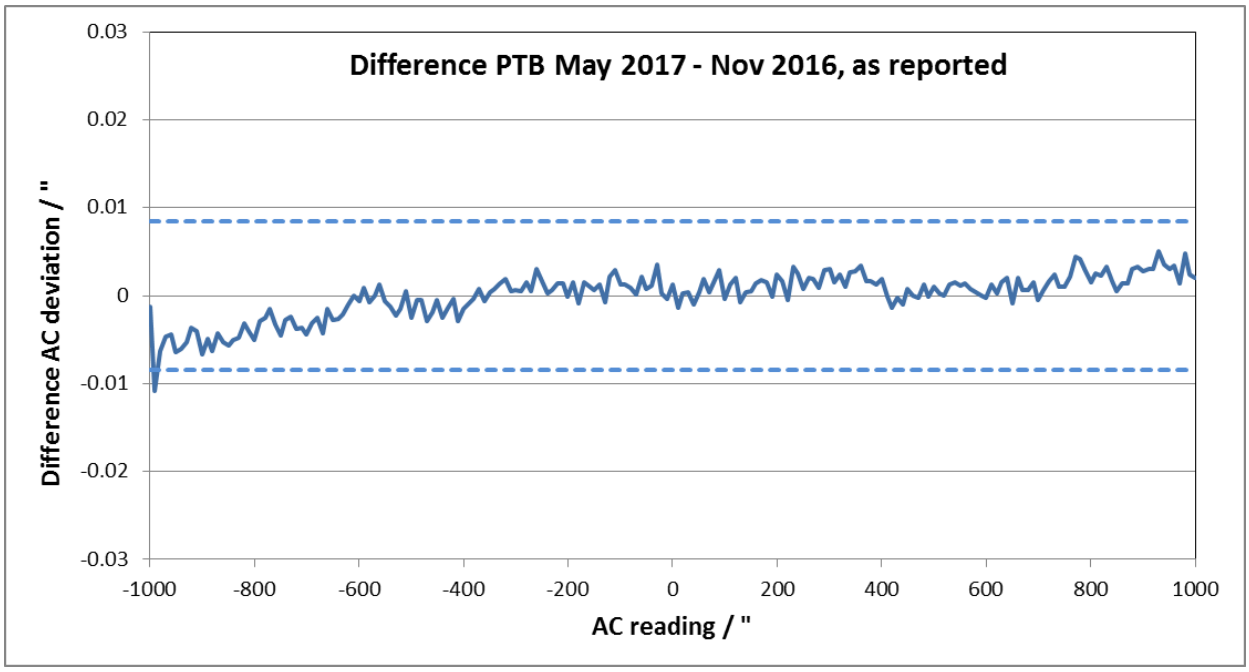

Figure 1. Difference with the expanded measurement uncertainty interval (dashed lines) of PTB calibrations in May 2017 and November 2016, without correction for the difference in atmospheric pressure.

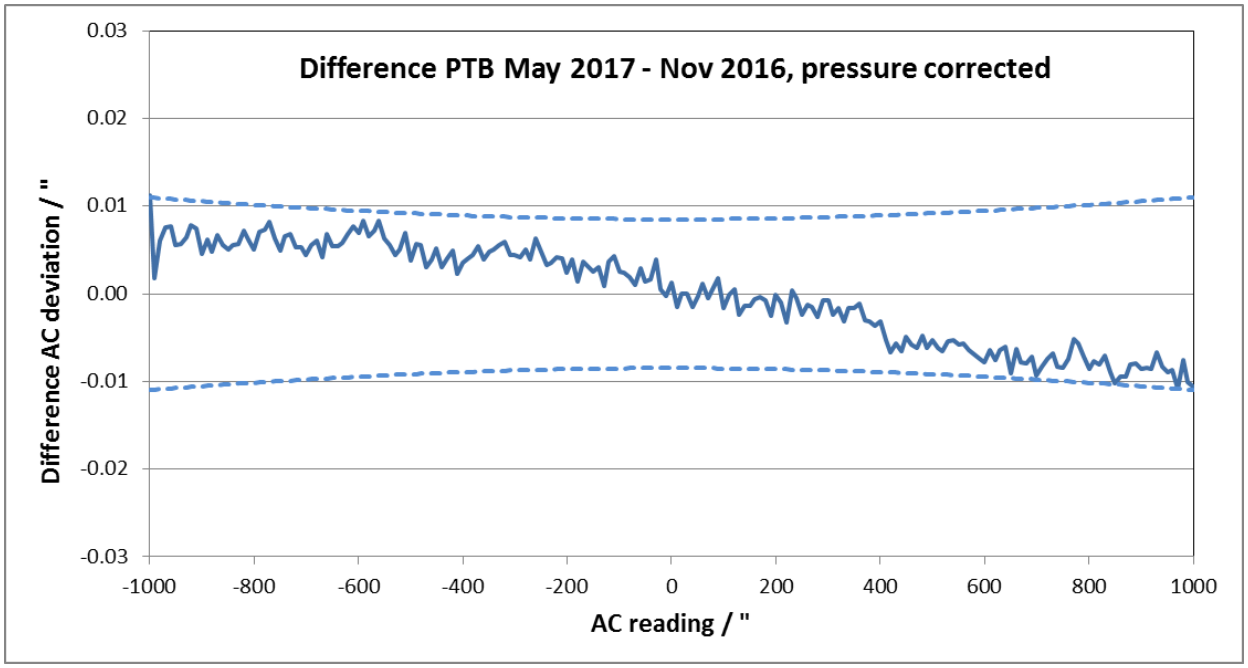

Figure 2. Difference with the expanded measurement uncertainty interval (dashed lines) of PTB calibrations in May 2017 and November 2016, with correction for the difference in atmospheric pressure.

5 Measurand

The measurand to be determined was the deviation δ of the angle measured by the autocollimator from the angle provided by the reference system according to

$$\delta = \alpha_{AC} - \alpha_{REF}, \quad (1)$$

with

δ : the angle deviation of the autocollimator,
α_{AC} : the angle measured by the autocollimator, and
α_{REF} : the angle measured by the reference system.

This had to be determined within the range of ± 1000" in steps of 10" and ± 10" in steps of 0.1". A Zerodur mirror was provided as reflector. The distance between the mirror and the autocollimator front lens was proposed to be 300 mm (equal to the focal length), a condition which was fulfilled by both participants. The entire illuminated (effective) autocollimator aperture (32 mm in diameter) was used.

6 Results

6.1 Results and standard uncertainties as reported by participants

The results were provided in units of arcsec in ASCII-tables according to a given format.

Figure 3 shows the results for the range ± 1000" as reported and Figure 4 after correction for the difference of atmospheric pressure with respect to standard pressure. For the purpose of the comparison, the May 2017 results of PTB were taken, since they were closer to the METAS measurement date. Figure 5 shows the results for the range ± 10" as reported.

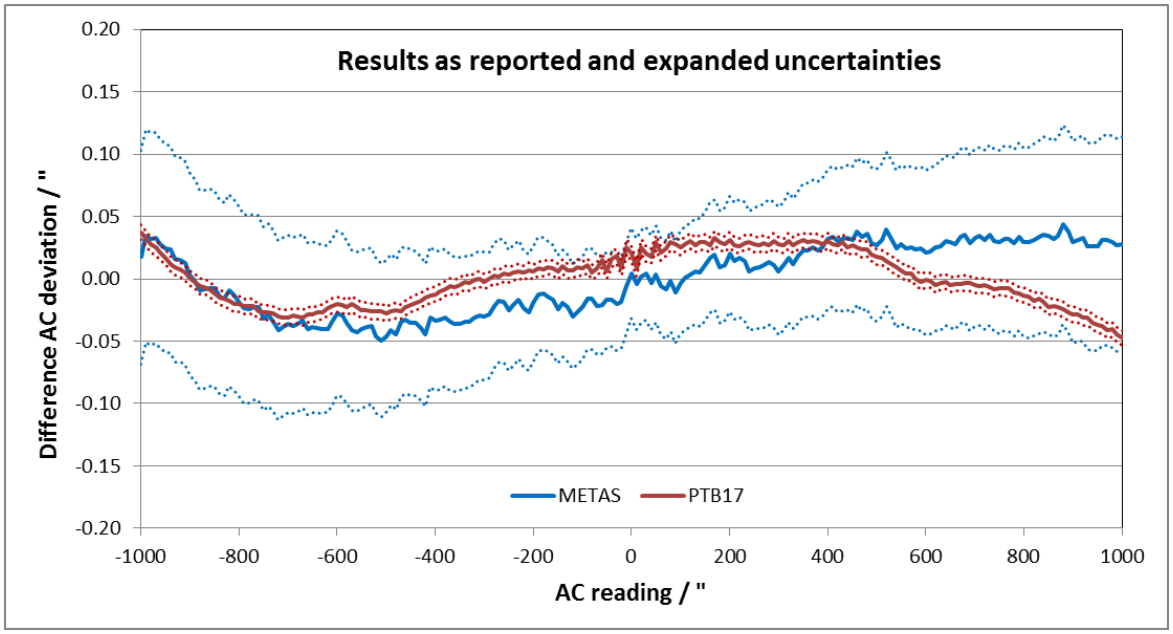

Figure 3. Results as reported from PTB and METAS together with the expanded measurement uncertainty interval (dotted lines) for the range ± 1000".

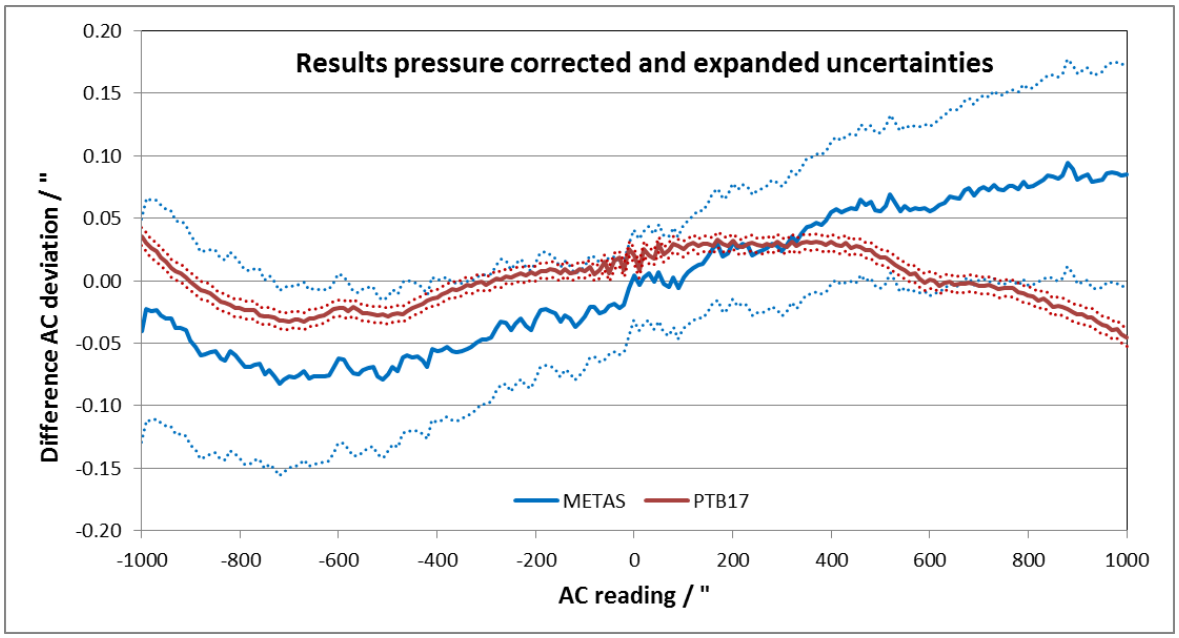

Figure 4. Results from PTB and METAS after correction for the difference of atmospheric pressure with respect to standard pressure together with the expanded measurement uncertainty interval (dotted lines) for the range ± 1000".

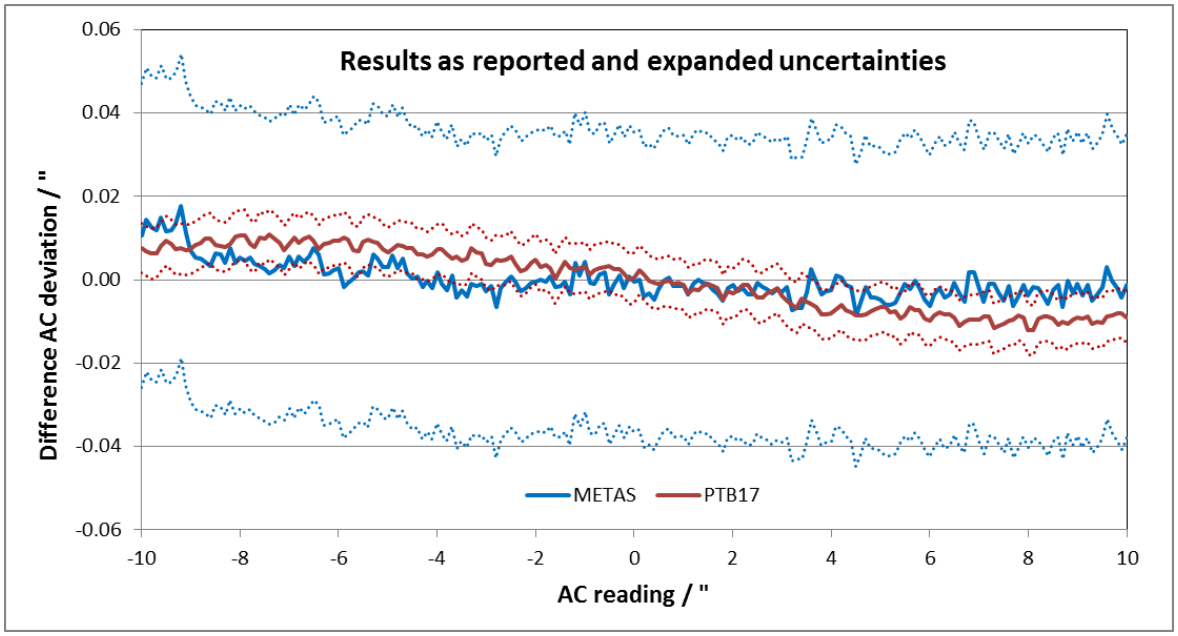

Figure 5. Results as reported from PTB and METAS together with expanded measurement uncertainty interval (dotted lines) for the range ± 10".

6.2 Measurement uncertainties

The following standard uncertainties were provided by the participants:

PTB: $u_c = 0.003"$, where k = 2.05 for 95% confidence interval
METAS: $u_c = 0.018" + 2.3 \cdot 10^{-5} \cdot |\alpha_{AC}|$, where k = 1.97 for 95% confidence interval

For simplicity, k = 2 is used throughout the analysis for calculating expanded uncertainies.

7 Analysis

7.1 Reference value and degree of equivalence

The calculation of a reference value makes no sense in a bilateral comparison. However, PTB's results may be considered as reference results, since they declare a considerably smaller uncertainty than METAS and their results were consistent with the key comparison reference values in the comparison EURAMET.L-K3.2009.

The Degree of Equivalence DoE between METAS and PTB are the difference $\delta_{METAS} - \delta_{PTB}$ and the expanded uncertainty of that difference $U(\delta_{METAS} - \delta_{PTB}) = 2\sqrt{u^2(\delta_{METAS}) + u^2(\delta_{PTB})}$. Equivalence is given as long as the absolute value of the ratio (E_n value) is smaller than 1:

$$|E_n| = \left| \frac{\delta_{METAS} - \delta_{PTB}}{2\sqrt{u^2(\delta_{METAS}) + u^2(\delta_{PTB})}} \right| \leq 1.$$

7.2 Pressure correction

In the report of EURAMET.L-K3.2009 it has been shown that the scale factor of an autocollimator is influenced by the atmospheric pressure. Following this suggestion the reported data of METAS and PTB were both corrected to standard atmospheric pressure of 1013.25 hPa using the following correction factor:

$$c = (0.91 \pm 0.1) ppm/hPa.$$

The uncertainty of the corrected results was increased taking into account the additional contributions as follows:

$u_{pc} = \sqrt{(c \cdot u_p)^2 + (u_c \cdot (p - p_{ref}))^2}|\alpha_{AC}|$, where

u_{pc} combined standard uncertainty of pressure correction
u_p pressure variation during measurement (standard deviation)
u_c standard uncertainty of correction factor c
p average pressure during measurement
p_{ref} standard atmospheric pressure
α_{AC} autocollimator reading

The participants reported the following average atmospheric pressure and pressure variation (standard deviation) during their measurements:
PTB: (1011 ± 2.3) hPa
METAS: (950 ± 11) hPa (550 m AMSL)

7.3 Degrees of equivalence of results as reported

Figure 6 and 7 shows the difference $\delta_{METAS} - \delta_{PTB}$ between METAS and PTB of the observed autocollimator deviations for the two ranges ± 1000" and ± 10" together with the expanded uncertainty $U(\delta_{METAS} - \delta_{PTB})$ of that difference.

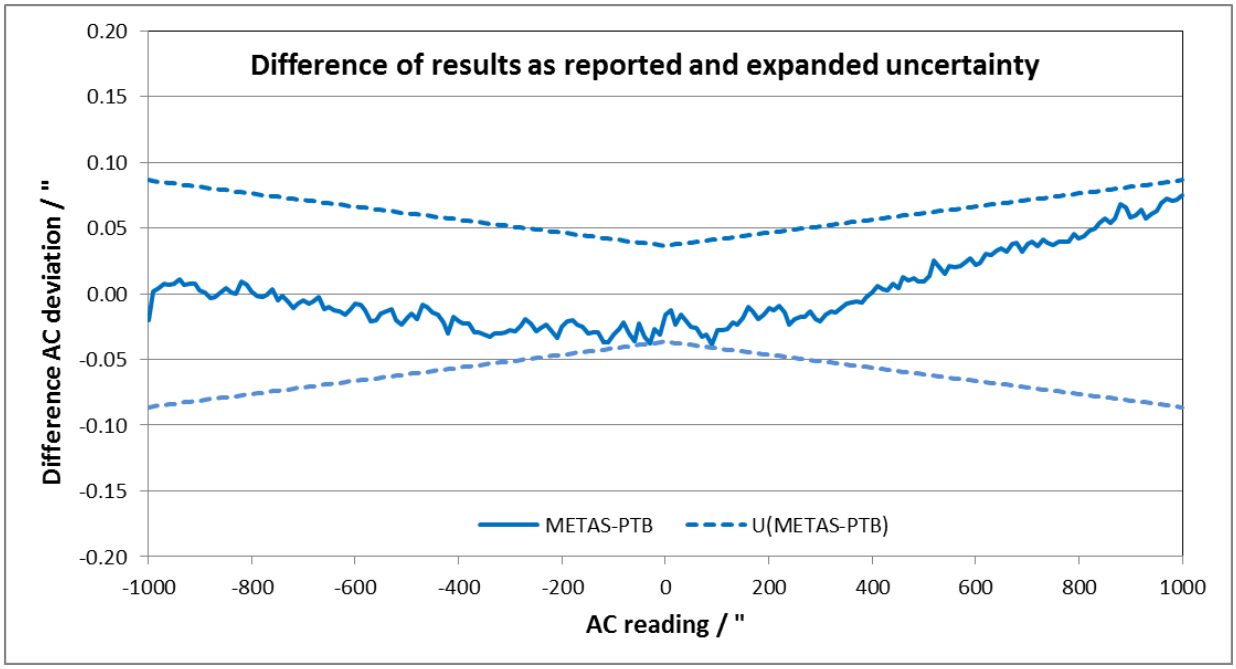

Figure 6. Difference between METAS and PTB of the observed autocollimator deviations and expanded uncertainty interval (dashed line) of that difference for the range ± 1000".

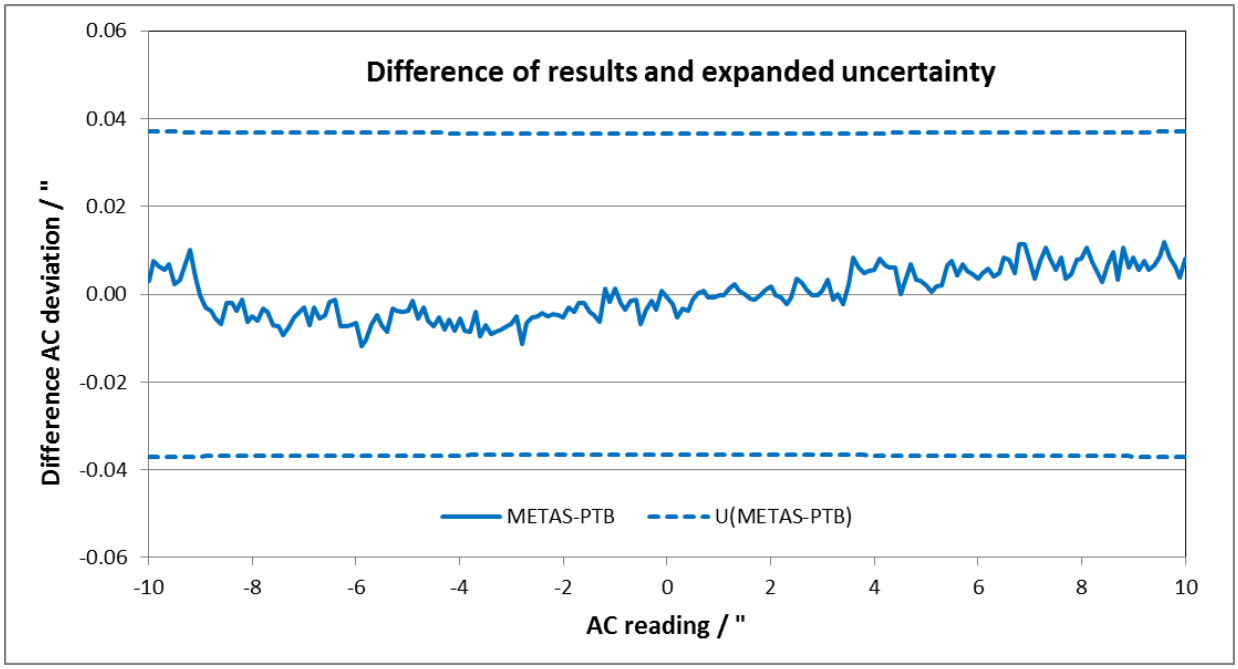

Figure 7. Difference between METAS and PTB of the observed autocollimator deviations and expanded uncertainty interval (dashed line) of that difference for the range ± 10".

7.4 Degrees of equivalence of results after pressure correction

Figure 8 shows the difference $\delta_{METAS} - \delta_{PTB}$ between METAS and PTB of the autocollimator deviations after correction to standard atmospheric pressure for the range ± 1000" together with the expanded uncertainty $U(\delta_{METAS} - \delta_{PTB})$ of that difference. The pressure corrected results for the range ± 10" were not evaluated since in this small range the atmospheric pressure has no significant influence.

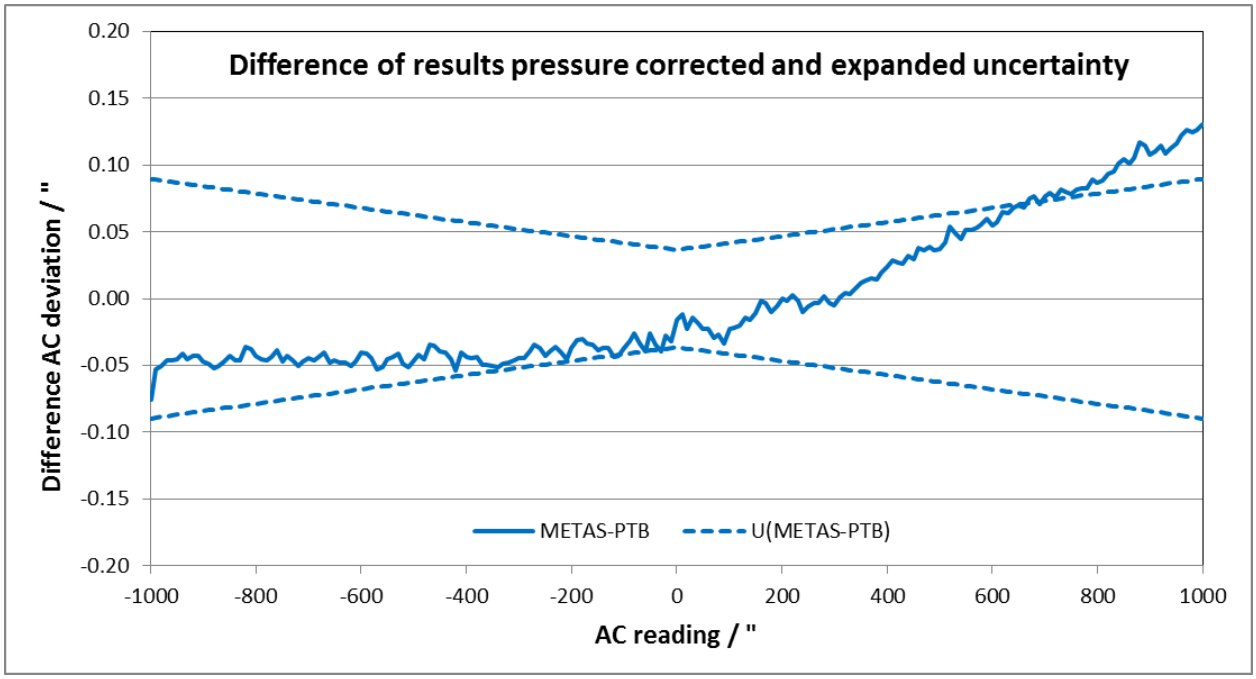

Figure 8. Difference between METAS and PTB of the autocollimator deviations after pressure correction and expanded uncertainty interval (dashed line) of that difference for the range ± 1000".

7.5 Degrees of equivalence expressed as En values

Figures 9 and 10 show the E_n values as defined in section 7.1.

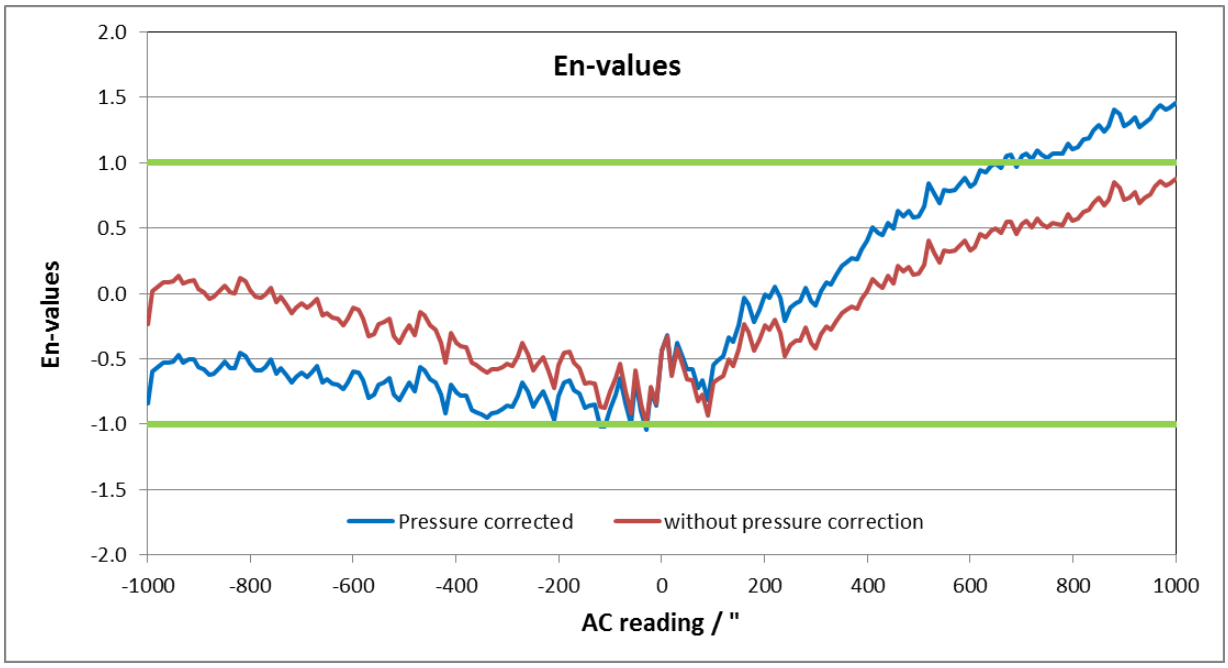

Figure 9. E_n values for the range ± 1000", with and without pressure correction.

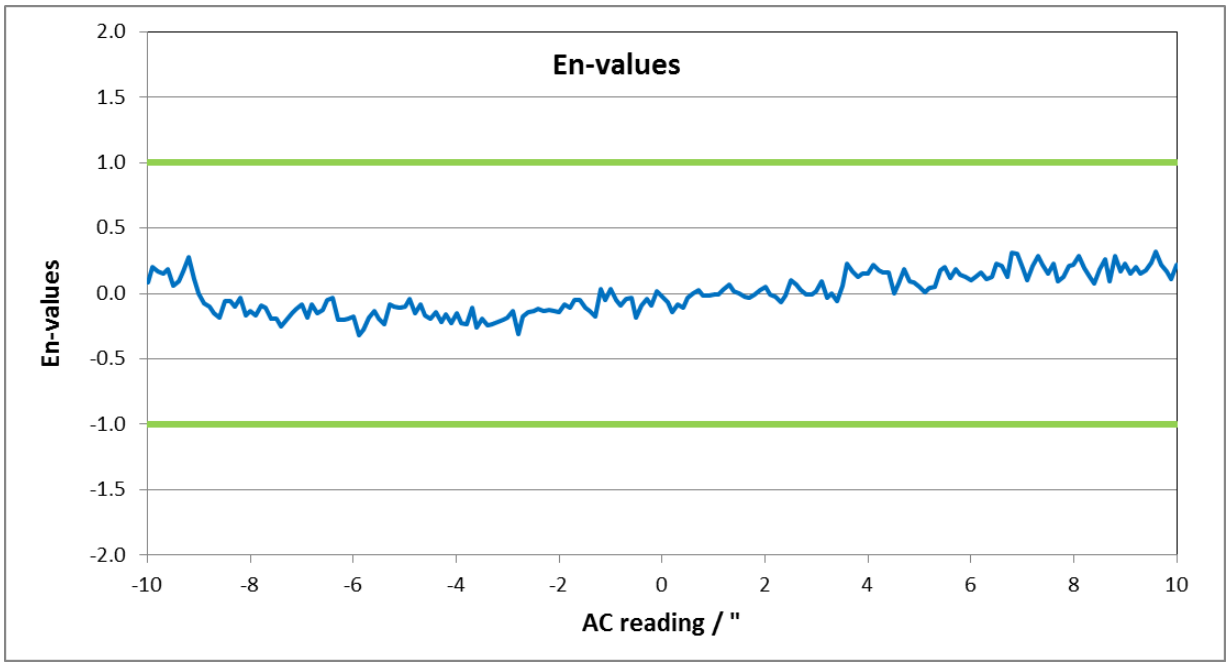

Figure 10. E_n values for the range ± 10".

7.6 Discussion of the results

The comparison results for the range ± 10" are very satisfactory with differences well within the quoted uncertainties. The results for the extended range of ± 1000" show at least that the periodic errors present in the METAS results of the original comparison EURAMET.L-K3.2009 could be removed. There is still a so far not explained error which is proportional to the absolute value of the AC reading, as clearly visible in Figures 6 and 8. METAS had detected some instabilities during their measurements, reason for having increased the uncertainty according to the expression given in section 6.2. In this comparison, the atmospheric pressure correction as suggested in the report of EURAMET.L-K3.2009 does not lead to a better agreement between the different results, as seen by comparing Figures 6 and 8, but also visible in Figures 1 and 2 of the PTB stability measurements. For this reason both uncorrected and pressure corrected results are shown in this report. However, within the stated uncertainties and the uncertainty contributions from the pressure correction, no significant conclusion can be drawn regarding the pressure correction. The degrees of equivalence for the pressure corrected results are still partly unsatisfactory, as seen in Figure 9 for AC readings above 700". Further measurements at METAS will be needed to investigate long term stability effects of the autocollimator calibration facility.

7.7 Linking of result to another comparison

The results are linked by PTB to the original comparison EURAMET.L-K3.2009, as outlined in section 7.1.